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A MICROSCOPIC INVESTIGATION OF MOLYBDENITE ORE FROM CLIMAX, COLORADO

LLOYD W. STAPLES AND CHARLES W. COOK, *University of Michigan.*

It is a well known fact that although the occurrence of molybdenum minerals is widespread, the deposits of economic value are very few; the one at Climax, Colorado, being the largest known deposit.

A microscopic study of a large suite of specimens from this deposit was undertaken in the hope that it might shed some light on the origin of this very important ore body. It is, therefore, not the purpose of this paper to present a detailed description of the many sections studied, but rather to record those observations which may possibly have a bearing on the question of the origin of the deposit.

LOCATION AND DEVELOPMENT

The camp of the Climax Molybdenum Company is located on the top of the Continental Divide at Fremont Pass, about fifteen miles northeast of Leadville. The town of Climax has an altitude of 11,300 feet, and the present working tunnel is about one mile east of the village at an altitude of 12,200 feet. There is a glacial cirque or amphitheater which opens toward the northwest at Fremont Pass and is bounded on the northeast by Bartlett Mountain and on the southwest by Ceresco Mountain. It is on the southwest flank of Bartlett Mountain that the principal outcrop of the ore occurs.

The Climax region was first prospected because of the discovery of rich gold placers in the district. In 1903 a tunnel 900 feet long was driven in the hope of finding gold but the venture was unsuccessful. Molybdenite was noted but little attention was paid to it, it being mistaken at different times for graphite and silver. In 1916 the American Metal Company, Ltd., examined the property and finding it to be a commercial deposit, started operations. Development was initiated in 1917 and February 1918

marked the first shipment of concentrates. In May 1918 the mill was treating 250 tons of ore per day, while at present with the new mill unit an average of about 2000 tons may be milled daily. This increase in capacity has not been uniform throughout the period, but has been marked by the fluctuations common to all enterprises.

The deposit at Climax is the largest known molybdenite deposit in the world and there are probably several hundred million pounds of elemental molybdenum represented in the mineralized area.

GEOLOGY OF DEPOSIT

The deposit was first discussed by Horton¹ who wrote, "In places where the snow had blown off, large quantities of slide rock were exposed, which on an average appeared to contain 0.5 to 1 per cent molybdenite, the mineral occurring in the cracks and fractures of a crystalline quartz, most of which was associated with more or less pyrite, but was practically free from copper minerals."

Two years later, in May 1918, Brown and Hayward² gave the following description of the deposit: "The eastern end of this amphitheater consists of a granite gneiss which has been intruded by the granitic rock in which the molybdenite deposits occur. The ore body is made up of a large, irregular-shaped mineralized zone having a siliceous phase of this granite intrusion. The rock in the ore body itself consists largely of quartz, with minor amounts of feldspar. This siliceous mass merges in all directions into typical granite. Throughout the mineralized zone, the rock is traversed by an intricate network of quartz stringers, which are undoubtedly of magmatic origin. The fact that the molybdenum is found both in these quartz veinlets and in the larger masses of quartz clearly indicates that it is genetically related to the granitic intrusive."

Haley,³ in a paper read in September, 1918, and published in 1920, said, "The high ridge forming the cirque is a coarsely crystalline biotite-gneiss. The alaskite is unquestionably an intrusive into the gneiss, and the latter at one time probably covered the

¹ Horton, F. W., Molybdenum; Its Ores and Their Concentration, *U. S. Bureau of Mines, Bull.* 111, p. 68, 1916.

² Brown, H. L., and Hayward, M. W., Molybdenum Mining at Climax, Colorado, *Engineering and Mining Journal*, May 18, 1918.

³ Haley, D. F., Molybdenite Operations at Climax, Colorado, *Trans. Am. Inst. of Min. Eng.*, Vol. 61, 1920.

whole area, but has been eroded from Bartlett and Ceresco Mountains."

Holland,⁴ in describing the deposit said, "The alaskite-granite has intruded an older gneiss, and a large zone in the alaskite-granite has been fractured and further silicified. Chunks of the gneiss are occasionally included in the alaskite-granite. Areas of quartz-porphyry containing little or no mineral also appear."

Worcester⁵ describes the rock into which the rhyolite porphyry has been intruded as a white even grained granite poor in muscovite and the ferro-magnesian minerals.

Hess⁶ says, "The origin of the ore is probably connected with the intrusion of a quartz porphyry, now so altered by sericitization and silicification as to be difficult of differentiation from the granites, large volumes of which are also altered in the same manner."

Evidence both from field observation and from microscopic examination indicates that there can be no question but that the ore body represents silicification of a portion of the Pre-Cambrian granite-gneiss complex. This idea was apparently held by Hess, but the theory expressed by Horton, Brown and Hayward, Haley, and Holland, embodying the idea of a later granitic or alaskite intrusion, seems to be opposed to the facts.

The question of the extent to which the extremely silicified portion of the deposit represents an alteration of granite, gneiss and schist is difficult to determine. In many instances sections of drill cores give strong indication of the silicification of gneiss or schist, rather than of granite. There is also evidence of the presence of a silicified quartz or rhyolite porphyry that further complicates the determination.

A sample taken from a drill core just north of the ore body and at a depth of 625 feet shows very good banding. A thin section from it contained much disseminated pyrite, a vein of pyrite and magnetite parallel to the banding, and many large grains of muscovite being altered to sericite. It seems probable that this specimen represents a highly sericitized gneiss.

⁴ Holland, L. F. S., Recent Developments in Molybdenum, *Mining and Scientific Press*, Oct. 19, 1918, pp. 529-531.

⁵ Worcester, P. G., Molybdenum Deposits of Colorado, with General Notes on the Molybdenum Industry, *Colo. Geol. Survey, Bull.*, 14, pp. 87-94, 1919.

⁶ Hess, F. L., Molybdenum Deposits, *U. S. Geol. Survey, Bull.* 761, p. 12. 1924.

The change of muscovite to the sericitic form (Plate I A) is, we believe, rather an unusual phenomenon. Clarke⁷ says, "The analyses of sericite usually show a small excess of silica over that



PLATE I A. Veinlet of orthoclase (O) cutting muscovite (M). The small laths on the muscovite are of sericite. Microphotograph with crossed nicols. $\times 100$.

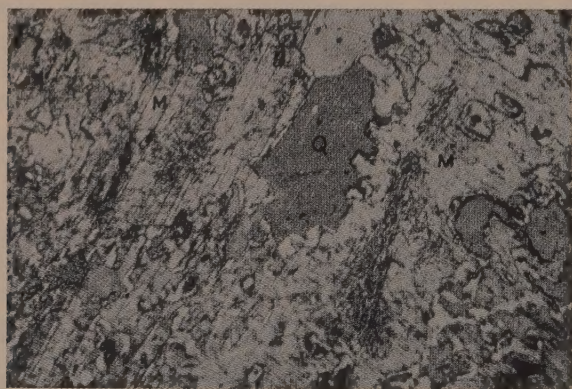


PLATE I B. Corrosion of muscovite (M) by quartz (Q). The quartz has followed the cleavage planes in the two differently oriented muscovite grains. Microphotograph with crossed nicols. $\times 100$.

contained in normal muscovite." It seems probable that the sericitic form may be more stable under conditions which tend to

⁷ Clarke, F. W., *The Data of Geochemistry*, U. S. Geol. Survey, Bull. 770, p. 605, 1924.

produce silicification. The fact that we do tend to have considerable sericite at Climax where the conditions are extremely siliceous would favor this possibility. The continuance of these siliceous conditions is evidenced by the fact that fresh quartz, which is later than the sericite and the muscovite, is found corroding and following the cleavage planes of the latter. This is clearly shown in Plate I B, where the direction of penetration of the quartz is completely influenced by the cleavage directions of the muscovite.

In the case of the granite the progressive silicification from unaltered granite to the intensely silicified material can be shown by a description of a series of typical specimens.

The unaltered granite is a biotite granite strikingly similar in appearance to the Silver Plume granite, with large grains of quartz, feldspar and mica, the latter chiefly biotite. Nearer to the ore body we find the quartz and the biotite persisting, but all the feldspar has been altered, retaining in many cases, however, its crystal form. A stage nearer to the ore body shows a complete loss of all the original crystal forms, the rock is brecciated, and the fissures are filled with quartz. The last stage, taken from the center of the ore body presents a highly silicified rock with only small areas of the altered original rock remaining between the siliceous veins. It is to be noted that there are two types of silicification; first, sharp cut silica veins; second, areas in which the rock has been silicified without regard to vein boundaries. The sharp cut silica veins are found to be most numerous in the less altered parts of the deposit. As the center of the ore body is approached the alteration becomes more intense and the areas of silicification without regard to vein boundaries are more prominent. In some cases practically the whole rock is highly silicified. Very often a hand specimen presents evidence of the quartz veinlets cutting across the silicified areas. Where it is not possible to see this megascopically, a microscopic examination will usually show it quite clearly. The significance of the relationship between sharp cut veins and silicified areas will be discussed later.

As already suggested, in the ore body proper, where the silicification is greatest, it is usually impossible to tell the type of rock that has undergone alteration. Examination of many sections has shown that there are at least three types of rocks that have undergone silicification: a gneiss, a granite, and a rhyolite or quartz porphyry. The altered porphyry is shown in Plate II A. A cor-

roded quartz phenocryst and sericitized areas, representing former feldspar grains, may be seen in the illustration.

In close association with the ore body is a rhyolite or quartz

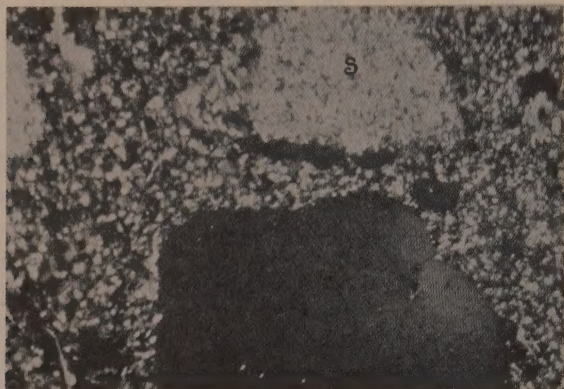


PLATE II A. Alteration of quartz porphyry. Large phenocryst of quartz surrounded by small grains of quartz and orthoclase. The lighter areas (S) are areas of orthoclase altered to sericite. Microphotograph with crossed nicols. $\times 50$.

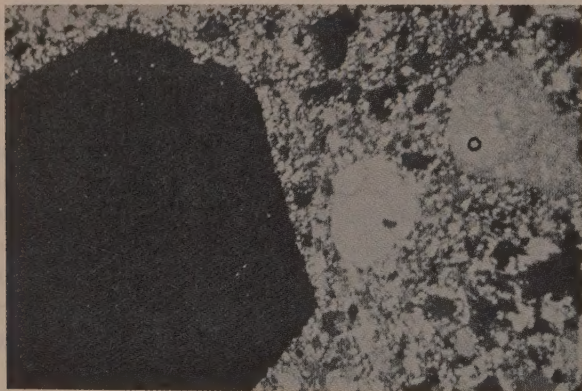


PLATE II B. Quartz or rhyolite porphyry with large euhedral quartz phenocryst (black). Orthoclase (O) shows slight alteration. Groundmass is of quartz and orthoclase. Note similarity to altered porphyry in Plate II A. Microphotograph with crossed nicols. $\times 50$.

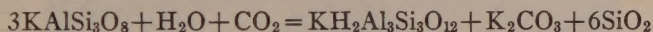
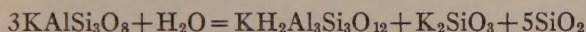
porphyry that is only very slightly altered. Microscopically it shows a striking resemblance to the altered porphyry described above and it may be that the latter represents an altered phase

of the rhyolite porphyry. Plate II B is a microphotograph of the unaltered rock and shows a large euhedral quartz crystal, with unaltered orthoclase in close proximity. A comparison with Plate II A shows the very great similarity.

Gradations in the silicification make an interesting microscopic study. In some of the rocks there still remains what seems to be the primary muscovite and biotite. A further stage shows only the feldspars remaining, but they are still in large grains. A still more altered stage shows just quartz and orthoclase but both of these minerals are fine grained and appear fresh, the orthoclase being usually finer grained than the quartz.

There are three possible sources for the very fine grained and fresh orthoclase. First, it may be due to the recrystallization of the original orthoclase. A second possibility is that it was brought in with the quartz, at the time of silicification, possibly as a eutectic mixture. There is a third possible origin, which is rather unusual, but is shown quite clearly to occur to some extent here. In order to obtain a clear understanding of this, it will be necessary to consider the formation of sericite from orthoclase.

Carbon dioxide or water may react with orthoclase to produce sericite and free silica, according to the equations:



The Climax deposit, especially in the upper part, has much sericite that was probably formed in this way.

A microscopic study of the specimens shows an occurrence that is interesting in this connection. In practically all of the cases where quartz has come into contact with the muscovite, a rim of orthoclase between the two has been produced. The rim is uniform in width and grades into the muscovite. It seems evident that the quartz has reacted with the muscovite to produce orthoclase, in other words, the above equations have been reversed. This reaction rim of orthoclase enclosing quartz is shown in Plate III A. Tyrell⁸ says that sericitization is reversible, especially with more intense thermal action. It is quite possible that a temperature change may have produced this reaction, but it seems better to explain it in the same way that the change from muscovite to sericite has been explained, that is, due to an environment with excess silica.

⁸ Tyrell, G. W., *Principles of Petrography*, p. 309.

The gases producing the sericitization would precede the silica. Later in an extremely siliceous environment, it seems probable that the law of mass action would operate to produce the opposite action.

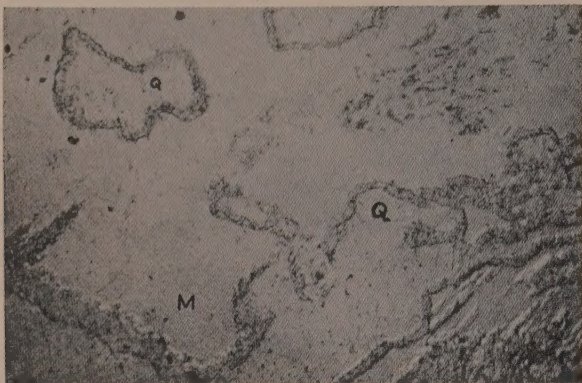


PLATE III A. Rings of fine grained orthoclase surrounding quartz (Q), and formed in the muscovite (M). $\times 50$.

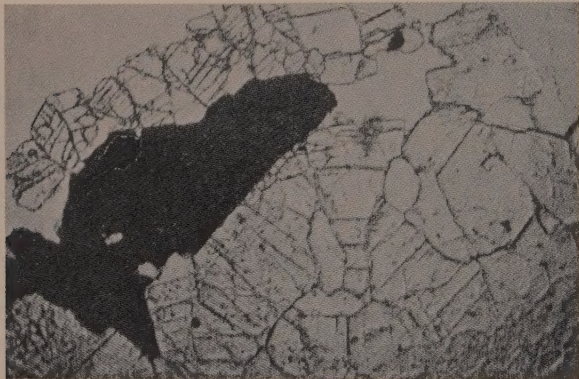


PLATE III B. Topaz showing basal cleavage and high relief. Opaque mineral is pyrite. $\times 50$.

How much of the fine grained orthoclase is to be explained in this way is very difficult to say, because in most cases all traces of muscovite and quartz have been removed. In Plate I A, the veinlet cutting the muscovite is almost entirely of orthoclase. If this veinlet is traced through the rest of the section it is found

to broaden out and the center becomes all quartz. This would indicate that originally there was a quartz vein which reacted with the muscovite along its borders. When the veinlet narrowed the reaction extended from edge to edge producing the effect seen in the plate, where the quartz is almost entirely lacking.

In Brown and Hayward's⁹ report, the statement was made that "No other minerals occur in the deposit with the exception of a small amount of pyrite." Undoubtedly, what was meant was metallic minerals. Since that report, and as noted by Hess,¹⁰ wolframite has also been added to the list. As a result of further study, a more complete list of the metallic minerals includes molybdenite, pyrite, chalcopyrite, molybdate, wolframite (possibly ferberite or huebnerite), and magnetite.

Among the non-metallic minerals of the ore body the following have been previously noted: Quartz, feldspars (altered), muscovite and sericite, biotite, fluorite, apatite, and rutile. To this list there may also be added topaz, which occurs extensively in the lower part of the deposit, and which has probably not been noted before because of the lack of microscopic study. Plate III B shows considerably topaz in association with pyrite. The importance of the topaz in the deposit and its possible significance will be discussed later.

FRACTURING OF THE DEPOSIT

There are two unique features of the Climax ore; first, the extreme brecciation, and second, the molybdenite differs from that of most other occurrences in that it is fine grained instead of being flaky, or coarse. The significance of each of these features will be considered separately.

Hess¹¹ states that "No uncracked piece containing as much as two cubic inches was seen in the main ore body." It is possible to count fifteen distinct fractures in a random piece of this size. The cause of the fracturing has been explained differently by the several geologists that have studied the ores. Brown and Hayward¹² attributed it to shrinkage on cooling. They say, "When the igneous mass was intruded into the overlying sediments, an outer shell was formed, attributable to quick cooling of the magma in

⁹ Brown, H. L., and Hayward, M. W., *op. cit.*, p. 906.

¹⁰ Hess, F. L., *op. cit.*, p. 11.

¹¹ Hess, F. L., *op. cit.*, p. 10.

¹² Brown, H. L., and Hayward, M. W., *op. cit.*, p. 906.

contact with the sediments. Shrinkage cracks and fractures were later formed throughout this shell, and these cracks and fractures were afterward filled with silica and molybdenite expelled from the gradually solidifying core of granite."

Haley¹³ postulates the same explanation for the fracturing as given above, and Hess¹⁴ does not offer any explanation.

There are many objections to the theory stated above, most of the objections being due to the fact that the theory was founded on the assumption that the main mass of the ore body represented a late intrusive into the Pre-Cambrian rocks.

Just what forces produced the intense fracturing has not been definitely determined. The present writers would suggest that there is a strong probability that the forces which were effective in producing the movement along the Mosquito fault, were also the cause of this intense fracturing. Why the fracturing should have been localized at this point, as it apparently has been, cannot be positively stated. However, the fact that the Mosquito fault changes the direction of its dip from east to west at or near this point suggests a plausible explanation. Such a change in direction of dip, in the case of a fault having such great displacement, would result in the development of large torsional strains. The relief of these strains would be accompanied by intense fracturing, just as glass under a torsional strain shatters when struck with a hammer. Daubree,¹⁵ in a series of experiments has shown the effect of torsion on glass and the effect produced is strikingly similar to the shattering in the Climax ore. The existence of strains seems to be corroborated by a microscopic study of the rocks. Very often the micas show torsional strain while the secondary quartz shows no strain at all and indicates that the silicification was subsequent to the straining and resultant brecciation.

NATURE OF ORE DEPOSITION

The ore at Climax occurs in a highly silicified zone, in which most of the rocks have been so altered by silicification that it is not possible to determine their original nature megascopically, and often it is not possible to do so microscopically. The rock

¹³ Haley, D. F., *op. cit.*, p. 73.

¹⁴ Hess, F. L., *op. cit.*

¹⁵ Daubree, August, *Études Synthétiques de Géologie Expérimentale*, Chapitre II, Paris, 1879.

is greatly brecciated and quartz veinlets carrying molybdenite are found following the fractures, producing a network of dark colored ore veinlets in a light colored silicified rock. Plate IV A shows a typical specimen of the ore. The tendency of the quartz veins to

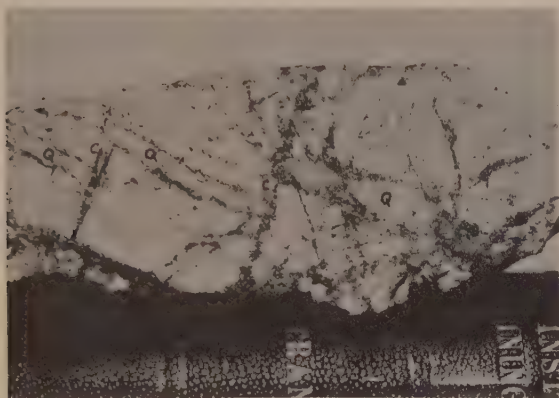


PLATE IV A. Specimen of ore showing veinlets with molybdenite concentrated along the borders. $\times \frac{1}{2}$.

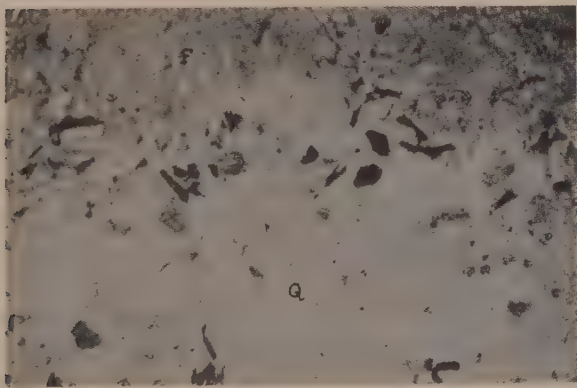


PLATE IV B. Microphotograph showing concentration of molybdenite (opaque mineral) along border of quartz veinlet (Q). Cloudy mineral (F) is feldspar. $\times 50$.

follow the fractures is seen in this illustration, in which it appears as though the quartz vein (Q) had been faulted but it is really continuous at (C) and follows the earlier fractures. In other parts of the deposit the ore is all so highly silicified that the individual quartz veinlets are not apparent.

It has been mentioned that topaz has been added to the list of minerals at Climax. However, this is not found in great amounts, although it seems to increase with depth. Above this there is a zone of extreme silicification which grades into a higher zone of sericitization. This distribution must be taken into account and explained by any satisfactory theory of ore deposition.

Although the fact that the molybdenite is extremely fine grained was noted by Brown and Hayward,¹⁶ they did not attempt any explanation of the fact, neither have any subsequent writers offered an explanation.

In this connection it is interesting to note that a German, F. Cornu, while studying the mineral ilsemanite, the composition of which according to Yancey¹⁷ is $\text{MoO}_2 \cdot 4\text{MoO}_3 \cdot 6\text{H}_2\text{O}$, searched in vain for the primary molybdenum mineral from which it had been derived. Later, it became apparent to Cornu that the ilsemanite had been derived from a black dusty colloidal sulphide of molybdenum, which he called jordisite,¹⁸ and which was included by Spencer¹⁹ in his fifth list of new mineral names. If Cornu's observations are correct, molybdenite may occur in the colloidal form. It seems very probable that the molybdenite at Climax was introduced in this form, since by postulating this method of introduction a much better explanation of the factors described above may be obtained.

The temperature above which colloids are stable will vary with conditions, but we may take the result of Königsberger²⁰ who obtained chalcedony from a silica gel at 350 degrees and, using this as the upper limit, conclude that quartz may crystallize from a silica sol or gel up to this temperature. Therefore our ascending solutions above this temperature, as they cooled, would precipitate the highest temperature mineral first, which at Climax is topaz, forming a bottom zone in which this mineral is concentrated. When the temperature fell to 350 degrees the silica might be considered to be in the colloidal state and with it the molybdenum sulphide as jordisite. With decreasing temperature there would tend to be precipitated the colloidal molybdenum sulphide. If

¹⁶ Brown, H. L., and Hayward, M. W., *op. cit.*, p. 906.

¹⁷ Yancey, *Chem. and Met. Engr.*, Vol. 19, p. 189, 1918.

¹⁸ Cornu, F., *Zeits. für Chemie und Industrie der Kolloide*, Vol. IV, p. 190, 1909.

¹⁹ Spencer, L. J., Fifth List of New Mineral Names, *Mineralogical Magazine*, Vol. 15, 1910.

²⁰ Königsberger, *Centr. Mineral. Geol.*, Nos. 11 and 12, 1906.

this were true the reason for the highly silicified zone below, and the sericitized zone above with clearly defined quartz veins, becomes apparent. Above 350 degrees the silica would be in solution and would be able to thoroughly impregnate the rocks. As the temperature decreased the silica would become colloidal and produce well defined veins with clear cut edges, since the poor state of dispersion would not permit easy impregnation. In this lower temperature zone, which is higher in the deposit, the gases would leave the colloidal veins and the carbon dioxide would react with the feldspars of the granite to produce sericite. The molybdenite would tend to be concentrated most in that intermediate zone where the silicification was giving way to sericitization.

Haley,²¹ in his paper on Climax says, "At the center of each veinlet very fine grains of molybdenite are visible to the eye, but toward the edges the grains become so fine as to appear simply as a dark coloration." A study of many specimens both megascopically and microscopically has indicated that Haley's statement does not generally hold true. If we study any clear cut quartz veinlet we find the molybdenite lining the two sides of the veinlet and becoming very scarce in the center. This is clearly shown in Plate IV A, where the dark coloration, due to the concentration of the molybdenite, is seen bordering the veins. The same thing is shown microscopically in Plate IV B, where the molybdenite, which is the opaque mineral, is seen bordering the quartz (Q). The clouded areas (F) are of altered feldspars.

The concentration of molybdenite as shown in Plates IV A and B, is another proof of the colloidal origin. The colloidal quartz and molybdenum would be confined to the vein and unable to impregnate the inclosing rock. Any gases, such as carbon dioxide and hydrogen sulphide, would be able to escape. They would tend to aid the migration of the molybdenum sulphide to the borders of the vein and it would there be deposited because of its relatively coarse colloidal state.

RELATION OF MINERAL ZONES

A study of specimens from different parts of the ore deposit at Climax indicates a regular zoning. However, this is not as easy to observe here as it is at many other places, because pyrite

²¹ Haley, D. F., *op. cit.*, p. 73.

is the only metal, besides molybdenite, that occurs in fairly large amounts, and this is of little assistance in determining zones because of its widespread range.

At depth there seems to be a topaz zone, which has already been mentioned. Above this is the ore zone proper and this may be divided into three parts; a lower zone of great silicification, a middle zone of less silicification and increasing sericitization, and an upper zone of greater sericitization in which most of the silicification is in the form of sharply defined silica veins. Above and beyond the ore body, there is decreasing silicification and some indication of the possible existence of a former tungsten zone. A consideration of the temperature relationships of the minerals involved will be necessary for an understanding of this zoning.

It is generally recognized that the oxides of tin and tungsten are formed at high temperatures, and these are usually associated with mineralizers, especially boron and fluorine. At lower temperatures the sulphides tend to be formed and the first of these is molybdenite, which shows a closer relationship with the oxides of tin and tungsten than with the sulphides. It is to be especially noted that in practically all of the cases where the normal sequence of tin, tungsten, molybdenum, is found, the pneumatolitic minerals topaz, containing fluorine, and tourmaline, containing boron, are present. However, J. Morrow Campbell²² describes a deposit at Tavoy in which these minerals are absent and it is an interesting fact that at Tavoy the deposition has been the reverse of the usual one, that is, we find tin later than tungsten and this later than molybdenum. Since, as has been mentioned, there is evidence of a tungsten zone above the molybdenite at Climax, the deposit may be somewhat analogous to the Tavoy deposits.

There are two possible explanations for the anomalous sequence in which tungsten apparently overlies molybdenite at Climax.

First, since colloidal behavior is different than the behavior of electrolytes in solution, it is possible that the molybdenite would coagulate from the gel before the tungsten. We have no direct proof of this, but further investigation might aid in clearing up the problem.

Second, since it is possible to explain the zoning quite well by postulating the normal sequence of deposition, in which tungsten

²² Campbell, J. Morrow. The Ore Minerals of Tavoy, *Mining Magazine* (London), Feb., 1919.

is a higher temperature mineral than molybdenite, from both solutions and colloids, this is to be preferred.

There are three stages of silicification in the deposit: At the lower depths of the deposit the ore is extremely silicified, presenting a glassy appearance; in the middle zone there is an increase in the number of veinlets, and these are rich in molybdenite; toward the top of the deposit, the silicified areas become fewer and sericitization is of increasing importance. The following theory not only accounts for the relative positions of tungsten and molybdenite, but also explains these stages of silicification.

As has already been described in this paper, the silicification is found in two distinct forms; sharp cut veinlets and silicified areas. It has been shown that the silicified areas were due to impregnation of the host rock by siliceous solutions at high temperatures, while the sharp cut veinlets were of colloidal silica at lower temperatures. Since we have both types of silicification in the same specimens, it indicates that the two conditions must have existed there, in other words, at any given locality there was entrance of material first at one temperature and later an entrance at a different temperature. A careful study shows that the sharply defined veins cut the silicified areas and are undoubtedly later. This means then, that a given locality was first under conditions of high temperature (let us say above 350 degrees) and later the conditions were those of a lower temperature (below 350 degrees), possibly due to a retreat of the magma below, or a cooling of it, resulting in a retreat of isothermal zones.

During the first period of deposition, tungsten was deposited in that zone which is now just above the surface, due to subsequent erosion. Whether above this we had molybdenite cannot be determined because it would have been removed by erosion. The silicification accompanying the tungsten was great at depth but decreased in amount toward the surface. In a later depositional period the molybdenite was deposited below the former tungsten zone, and there were various types of silicification accompanying it. At depth there was great silicification due to the ability of the highly heated solutions to permeate the rocks. Nearer to the surface and due to the lower temperatures the silica was in the colloidal form and followed the fractures, producing sharp cut veinlets. Considerable sericitization accompanied this phase.

If we superimpose the results of these two depositional periods

upon each other, the result is just what is found at Climax. At depth there would be extreme silicification and production of a glassy appearance, since there was great silicification during both periods. Higher up, and in what might be called a central zone, there would be the silicification of the first period cut by the sharp veins of the second period. As one moves up from this, the silicification of the first period decreases, whereas the importance of the veinlets and sericitization increases. The main molybdenite zone occurs at this point. Above this and in a zone now eroded, the tungsten deposition took place. Thus by considering the composite effects of the two depositional periods, which were probably just phases of the one period, caused by a retreating or cooling magma, the zoning is well explained. Although it is not absolutely essential to use the colloidal theory for veinlet formation in the above explanation, the sharp cut veins seem to be best explained in this way for reasons that were brought out in the discussion of the nature of the ore body.

CONCLUSIONS

The facts presented above indicate that there is a basis for drawing the following general conclusions:

1. The fracturing which preceded the formation of the deposit was most likely the result of the same forces which were involved in the production of the Mosquito Fault, whereas the localization of the intense fracturing was probably due to the development of torsional strains accompanying the reversal of dip of the Mosquito Fault.

2. The highly altered rocks of the deposit are the result of recrystallization, silicification, and sericitization of granites, gneisses, and quartz or rhyolite porphyries.

3. There are areas of general silicification and also sharp cut silica veins. It seems probable that the former were produced at high temperatures with an abundance of mineralizers. The sharp cut veins may best be explained by a colloidal origin at lower temperatures.

4. The ore was introduced subsequent to the fracturing of the deposit and was aided in its migration by the fractures. The molybdenite is associated with the quartz veinlets and accompanied the silicification. It is possible that the colloidal theory which explains the quartz veinlets also holds for the molybdenite, since the mineral is known to occur in the colloidal form.

5. There is a zonal arrangement in the deposit. At depth there is a highly silicified-topaz zone; above this the silicification decreases and well defined quartz veins become apparent, sericite increasing as the silicification decreases.

6. Topaz has been found in the rocks, especially those from the deeper zones. Further petrographic study would probably be able to relate this with a definite zone in the deposit, which would aid in studying movements along faults and in indicating the limits of ore deposition.

ON CRYSTALLOGRAPHIC CLASSIFICATION

VICTOR GOLDSCHMIDT, *Heidelberg*¹.

FORM-SYSTEMS AND CRYSTAL-SYSTEMS

Every crystal species has its *form-system*, which includes all the morphological structures known to the species. These include growth- and solution-structures. Each crystal species has its growth-form-system and its solution-form-system. The two together constitute the form-system of the crystal species. The general scope of morphology is the study of these structures, which means the study of all form-systems.

Until recently, only the *growth-structures* were objects of morphological study, and at first only plane faces with edges and coignes were considered. Later, curved growth-structures and growth-accessories were included. My *Atlas der Kristallformen* (1913–23) records almost exclusively plane-faced growth-structures; it is these which form the foundation of our morphological knowledge.

Of *solution-structures*, only accessories, etch-pits and etch-ridges, were at first the objects of observation; only in 1903 were the solution-bodies from the sphere included.²

Classification referred at first to the growth-form-systems; it appeared, however, that another classification was not necessary for the solution-structures. The same classification serves for both. This is a valuable unification. Even to-day our **crystallographic classification** is a classification of **crystal forms**. This is not self-evident. One could also classify crystals according to other properties, such as chemical, optical, thermal or röntgenographic, according to the properties of the crystal-building particles.

A classification according to the properties of the crystal-building particles would have the advantage of a close relationship with our definition: "*A crystal is a rigid system of similar, similarly oriented particles.*"³

It would be in error, however, in that the particles comprising the structures are not directly observable; indeed their existence, and hence the definition, has been questioned.

¹ Appeared first in German: VICTOR GOLDSCHMIDT, "Zur kristallographischen Systematik," *Cb. f. Min.*, 1930, A, pp. 177–190, figs. 1–6. Translated into English, at Professor Goldschmidt's request, by M. A. Peacock, Vancouver, B. C.

² V. GOLDSCHMIDT AND F. E. WRIGHT, *N. Jb. f. Min.*, Bl. Bd. **XVII**, p. 355, 1903; **XVIII**, p. 335, 1904.

³ V. GOLDSCHMIDT, *Ostwalds Ann. Nat. Phil.*, **9**, p. 372, 1910 (trans.).

A classification according to chemical properties fails with crystals since the objective of chemistry is the structure of the molecules, while crystals are built of particles.⁴ Chemically, one cannot distinguish rutile, anatase and brookite; all three are forms of titanic acid. Calcite is indistinguishable from aragonite; both are carbonates of lime.

Optical properties fail with opaque minerals. The röntgenographic properties are still but little understood. They will probably not suffice for a comprehensive classification of all crystal species; at present they are certainly inadequate.

Thus morphology, the crystal forms and the form-systems with growth- and solution-structures, remains as the basis of crystallographic classification.

And so the classification of crystals is equivalent to classification according to their **form-systems**. Each crystal species has its proper form-system which is peculiar to the species, and is the material of morphological study.

The morphological properties of crystals have the advantage over all other properties in giving the largest amount of information on the growth and solution of crystals, their formation and decay, and the nature of the operating forces and movements.

Definite relations exist between the morphological and the remaining properties of crystals. In a classification, these relations should be taken into consideration, in accordance with the following acceptance: *A Morphological classification should accord as well as possible with the remaining properties, as far as they are known.*

As we saw above, a classification of growth-structures is at the same time valid for solution-structures. We include the two in the collective conception, form-system. We then arrive at the conclusion: **A Classification of crystals is a classification of their form-systems.** Among these, the growth-forms are the most important as they are better known and our knowledge of them will increase. Solution postulates growth; the reverse however does not hold.

The plane-faced structures are the groundwork of the growth-structures, and until recently they were the exclusive objects of morphological study. Indeed, the definition was: "A crystal is a natural body bounded by plane faces."

According to this a crystallographic classification was a classi-

⁴ V. GOLDSCHMIDT, *Zs.f. Krist*, **17**, p. 25, 1889.

fication of plane-faced crystals. Now curved structures also belong to the form-system.

Each crystal species has its plane-faced form-system which is completed by the addition of the curved faces. Now it has appeared that the classification for plane faces has also served satisfactorily for the classification of collective form-systems (including accessories and curved structures). Thus our classification is given further simplicity and precision. We come to the conclusion that: *A classification of crystals is a classification of their plane-faced form-systems.*

The following questions arise: What is characteristic of a form-system? What property is common to them all? What distinguishes one from another?

By projecting all the observed forms of a crystal species we obtain a view of the complete form-system. We call this a complete projection-diagram (Gesamtprojektionsbild). At this point the gnomonic and the stereographic projections come into consideration. The former has the advantage in that we can read (measure) the elements and symbols from it. We conclude therefore that: *The characteristics of a form-system are the characteristics of its complete gnomonic projection-diagram.*

The development of forms appears in the complete gnomonic projection in the following manner:

From a few points, the *primary nodes*, zones (primary zones) extend from primary node to primary node. In every zone further nodes (derived nodes) develop after the Law of Complication according to the harmonic numbers:

p=0	.	.	.	1	.	.	.	∞
p=0	.	$\frac{1}{2}$.	1	.	2	.	∞
p=0	$\frac{1}{3}$	$\frac{1}{2}$	$\frac{2}{3}$	1	$\frac{3}{2}$	2	3	∞

The node 1 we call the *dominant*. The dominant of a primary zone we call a *primary dominant*.

Secondary zones extend from primary nodes to primary dominants; tertiary zones between two primary dominants; further derived zones between derived nodes. The development in every free zone-segment follows according to the Law of Complication, as indicated above. This development is common to all form-systems; it constitutes the given foundation of the classification. The

primary nodes are diagnostic and characteristic of single form-systems.

We characterize a form-system according to the number and arrangement of the primary nodes in the gnomonic projection.

The faces corresponding to the primary nodes (principal nodes) are in all crystal species so common and developed to such an extent that they (or some of them) are found on almost every single crystal. Accordingly, measurement and projection of a small number of crystals, indeed usually of a single crystal, suffices roughly to characterize the form-system of the species. This rough characterization forms the outline of our classification.

The characterization of the principal nodes follows, as from every other face-pole, from their co-ordinates referred to suitably chosen co-ordinate axes in the gnomonic projection, measured with suitable unit lengths ($p_0' q_0' h=1$), from a conveniently chosen origin.

The axial direction and the origin are characterized by the axial angle ν and the co-ordinates of origin ($x_0' y_0'$). The quantities $p_0' q_0'$ ($h=1$) $x_0' y_0' \nu$ are called the projection elements. They are at the same time the projection elements of all forms derived from the primary nodes, and thus of the entire form-system.

In choosing the axes the following is to be kept in mind; the axial direction should follow a principal zone; the origin shall lie, if possible, at the pole; the axial angle ν shall be, if possible, 90° or 60° .

We make the statement, the **characterization of a form-system** is given by the projection-elements of the principal nodes, which are at the same time **elements of the form-system**:

$$p_0' q_0' (h=1) x_0' y_0' \nu$$

We distinguish six cases:

	Crystal system	p_0'	q_0'	h	x_0'	y_0'	ν
1	Regular.....	1	1	1	0	0	90°
2	Hexagonal.....	p_0'	p_0'	1	0	0	60°
3	Tetragonal.....	p_0'	p_0'	1	0	0	90
4	Rhombic.....	p_0'	q_0'	1	0	0	90
5	Monoclinic.....	p_0'	q_0'	1	e'	0	90
6	Triclinic.....	p_0'	q_0'	1	x_0'	y_0'	ν

The six possibilities we call the **six crystal systems**; there is no seventh. We find the crystal system directly from measurement and projection, and thus we can place every crystal species into one of the six systems.

The six crystal systems thus defined constitute the foundation of the morphological classification, and, as shown above, of crystallographic doctrine. There is no better foundation. The crystal systems are characterized, as above, by the projection elements. We can express the elements as:

Polar elements: p_0q_0 ($r_0=1$) $\lambda\mu\nu$

Linear elements: a_0b_0 ($c_0=1$) $\alpha\beta\gamma$ or $a:1:c$; $\alpha\beta\gamma$

We may assume that the details are known.

The form-system of each crystal species is characterized by the special values of the elements in so far as these are variable. The length 1 and the angles 90° and 60° are invariable.

The **number of variable elements** is characteristic for each crystal system.

	Variable elements
Regular system.....	0
Hexagonal system.....	1
Tetragonal system.....	1
Rhombic system.....	2
Monoclinic system.....	3
Triclinic system.....	5

According to this we can characterize the crystal systems by the number of variable elements: 0.1.2.3.5. In this way the two systems, hexagonal and tetragonal, fall together as uniaxial, and are distinguished by the angle ν . This grouping has its advantages, as both are optically uniaxial.

The form-system of each crystal species has its own peculiarity; there are no two crystal species in Nature with the same form-system. The study of the form-systems of all known crystal species is the problem of morphology.

Each crystal species with its form-system belongs to one of the six crystal systems. Calcite is hexagonal; topaz is rhombic. By giving the values of the elements (*e.g.* topaz: $p_0q_0=1.8049$; 0.9539), the requirements of classification are largely satisfied.

The form-system of each crystal species, and thereby the crystal species itself, is broadly described by its **crystal system, elements**

and symbols. The table of forms with symbols and angles (angle-table), and the complete projection-diagram (gnomonic, stereographic, perspective), give us a comprehensive view.

The catalogues of forms, *Index* (1886-1891), *Winkeltabellen* (1897), and the *Kristallographische Projektionsbilder* (1897) of the author, and many single works, assist in this comprehensive view. Since then our knowledge of crystal systems has made great progress, and the development of the field still continues. The form-systems are being critically clarified and supplemented by new typical forms and by growth- and solution-accessories giving information on the origin and decay of crystals.

But the new observations have not altered the picture of the form-systems in its broad outlines. The rich and the poor form-system alike fits freely into one of the six crystal systems, is governed by elements, and is represented by symbols and projection-diagrams.

DIVISIONS OF THE CRYSTAL SYSTEMS

Divisions of the crystal systems may be constructed in the following manner:

The gnomonic diagram of each form-system shows a division into fields. The elements show, gnomonically, this same division. Every crystal system has its peculiar field-division; these are given in figures 1-6.

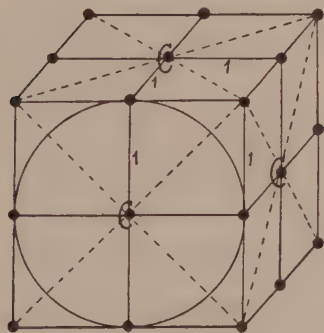


FIG. 1. Regular,
24 symmetry-fields.

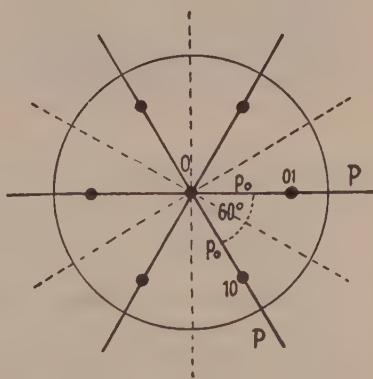


FIG. 2. Hexagonal,
12 symmetry-fields.

We designate similarly-shaped fields, bounded by zone-lines passing through the pole of the gnomonic diagram, as *symmetrical fields*. We have in the hexagonal system 12, tetragonal 8, rhombic

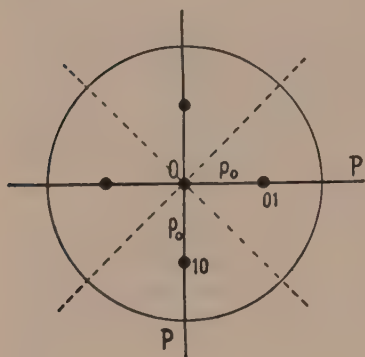


FIG. 3. Tetragonal, 8 symmetry-fields.

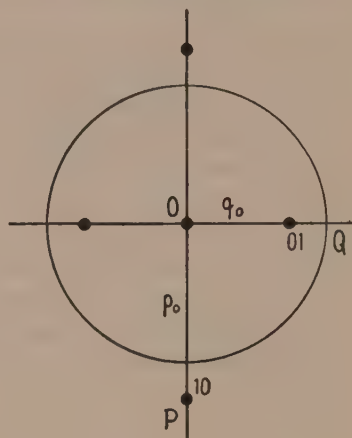


FIG. 4. Rhombic, 4 symmetry-fields.

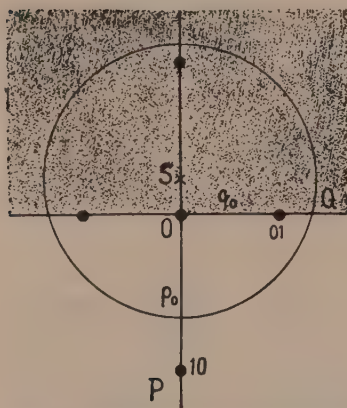


FIG. 5. Monoclinic, 2 symmetry-fields.

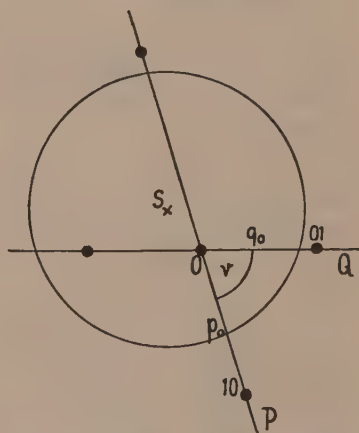


FIG. 6. Triclinic, 0 symmetry-field.

4, monoclinic 2, and triclinic 0 symmetrical fields, and in addition the counterfields of the lower projection-plane. In the regular system the 24 similarly-shaped fields of the projection on the polar form (cube), with their counter-fields, are symmetrically distributed.

We make divisions of the crystal systems according to the equivalence of the symmetrical fields.

Equivalent fields may be defined as symmetrical fields occupied by equivalent points.

In each crystal system we distinguish between:

Holohedrisism: equivalence of all the symmetrical fields.

Hemihedrisism: " " half of the symmetrical fields.

Tetartohedrisism: " " one fourth of the symmetrical fields.

Hemimorphism: non-equivalence of the upper and lower projection-fields.

For the types of hemihedrisism we have the following subdivisions:

- | | | |
|---|---|--|
| A | { | F = G: field and counter-field equivalent. |
| | | F = G: field and counter-field non-equivalent. |
| B | { | Equivalent fields alternating in quadrants, |
| | | " " " in pairs, |
| | | " " " singly. |

For the details you are referred to the author's papers: "Über Kristallssysteme, deren Definition und Erkennung,"⁵ and "Über Abteilung der Kristallsysteme."⁶

THE THIRTY-TWO SYMMETRY CLASSES

In 1899 I wrote the following:⁷

"Until recently, the six crystal systems constituted the undisputed primary grouping of crystals, the foundation of crystallographic classification. The hemimorphisms and hemihedrisisms appeared as subdivisions. Lately there has been a strong tendency to throw the six systems overboard and place thirty-two symmetry classes in their stead.

"This movement, which intrudes didactically, introduces a new nomenclature, and also influences the course of investigation, was notably furthered by the fact that P. GROTH adopted the divisions according to classes in his widely used *Lehrbuch der physikalischen Kristallographie* (Ed. III, 1895) and in his *Tabellarische Übersichte* (1898).

"Other crystallographers have done likewise, and it appears as if most of those who have not already done so would follow—most of them probably with an uneasiness which is particularly evident in teaching; and as the result many accept the thirty-two classes in principle, but retain the six systems and their divisions for instruction and for their own use."

⁵ *Zs. f. Krist.*, **31**, p. 135, 1899.

⁶ *Zs. f. Krist.*, **32**, p. 49, 1899.

⁷ *Zs. f. Krist.*, **31**, p. 135, 1899 (*trans.*).

Since then thirty years have passed. In that time crystallography, especially morphology has made great progress. I have followed the development as observer and collaborator, and now I again ask the question: *Is it proper in a crystallographic classification to retain the six crystal systems and their divisions (A), or the thirty-two symmetry classes (B), or to carry A and B side by side?*

We shall first decide that to carry two classifications, A and B, side by side would not be desirable; it would be an unnecessary burden, and particularly onerous if both classifications were to be inflicted on the beginner. So either A or B must be dropped; but which shall it be? On general principle, we may say:

Of two classifications, one must decide; (a) Is one better? (b) Is one indispensable? We shall examine the question from these aspects, and attempt to reach a decision.

Question (a): Is A better than B?

Against B we may bring the following arguments:

1. The postulated symmetry is not found on the forms of crystals.
2. Symmetry is a bad classificatory principle for crystals.
3. Six units of classification can be viewed at once, but not thirty-two.
4. No given crystal can be placed in one of the thirty-two classes on the basis of measurement.
5. The thirty-two classes are pedagogically difficult.
6. Measurement, without which a crystal cannot be classified, according to A or B, gives first the crystal system and sometimes the division, but never the reverse.

For B the following is contended:

7. The thirty-two classes may be derived from a single principle.
8. One can derive the thirty-two classes from the principle of symmetry without being acquainted with the forms which nature offers. Since there are no other possibilities (on this principle), natural structures, both known and as yet unknown, must fit into the system.
9. A more important relation exists between the thirty-two classes and the physical properties of crystals than between the crystal systems and the physical properties.

We shall examine these arguments singly.

Arguments against B.

1. *The postulated symmetry is not found on the forms of crystals.* Among the thousands of topaz crystals that I have handled, I have not found a single one showing the required symmetry. Of the required eight faces for $u = \frac{1}{2}$, or $o = 1$ of topaz, more than four faces were seldom present, and these were never of equal size. The same holds true of the remaining forms of topaz; in like manner for calcite, quartz, pyrite; in brief, of all the crystal species that I know. I can assume with certainty that no other crystallographer has had contrary experience.

This argument alone should suffice to rule out symmetry as the main, indeed the only classificatory principle.

2. *Symmetry is a bad classificatory principle for crystals.* A good systematic principle allows the simple to appear simple, the complicated to appear complicated. But the symmetrically simplest crystals (triclinic) are in every other respect the most complicated, while the symmetrically most complicated (regular) crystals are in every other respect the simplest.

3. *Six units of classification can be viewed at once but not thirty-two.* Our ability of simultaneous apprehension reaches three, at most five units. Even six oversteps the limit, and six systems can be viewed simultaneously only by separation into three groups.

1. Regular.

2. Uniaxial: hexagonal, tetragonal.

3. Biaxial: rhombic, monoclinic, triclinic.

The divisions, also, are small in number:

holohedral, hemihedral, tetartohedral;

hemimorphic.

No group has more than three components; this is a simple arrangement, and simultaneously visible.

Thirty-two co-ordinating unities are never simultaneously visible. One can make them so by a grouping according to corresponding relations. By doing so, one arrives at the crystal systems and their divisions by a laborious detour, which is not necessary.

4. *No given crystal can be placed in one of the thirty-two classes on the basis of measurement.* Having measured a calcite crystal, I can determine the crystal system easily and with certainty, also the division (hemihedrism), the elements and symbols. The symmetry class I cannot determine at all. The same holds true for all

crystals. Neither knowledge nor experience helps us over this impossibility.

5. *The thirty-two classes are pedagogically difficult*, even though a number of distinguished mineralogists and non-mineralogists have tried to make them more acceptable by means of suitable nomenclature and synoptical tables. Having mastered them, the student finds the path difficult in transferring to the crystals in Nature.

If he wishes to overcome the contradictions, he has no choice but to go to Nature and measure and discuss crystals for himself. If he does this, he arrives, on the basis of measurement, at the crystal systems, the elements and symbols, and eventually at the division. He fails wholly to find the symmetry class which he was seeking to understand clearly, and so the contradictions remain for him unsolved.

It would be particularly inappropriate to introduce the thirty-two symmetry classes in the school (or college) and equally bad to have one classification for the school and another for the university.

6. *Measurement without which a crystal cannot be classified, gives first the crystal system and sometimes the division, never the reverse.* If the co-ordinated thirty-two classes be arranged, and several of them included (for simultaneous inspection) in one crystal system, one attains the simple and positive (the crystal systems) by grouping the complicated and doubtful (the symmetry classes). This is irrational. Instead, the attainment of what is most certain and comprehensive is to be recommended first and then (if desirable or possible), the separation of the simple divisions into still smaller subdivisions; that is the rational procedure.

Arguments for B.

7. *The thirty-two classes may be derived from a single principle.* This statement was cited as an advantage and placed at the head of the publication by A. Gadolin,⁸ in which he introduced the thirty-two classes into systematic crystallography, and others have adopted it. But it is not an advantage to derive the system of a richer domain of Nature or of Art from a single field. And this is even less desirable the farther our knowledge progresses.

⁸ Deduction d'un seul principe de tous les systèmes cristallographique avec leur subdivisions, *Act. Soc. Fennic. Helsingfors*, 9, pp. 1-71. (1867), 1871.

In other sciences we do not proceed thus. Zoology divides animals into vertebrates and invertebrates (according to the presence or absence of vertebrae), and the vertebrates are divided into mammals, birds, reptiles, amphibians and fishes, not according to the vertebrae but according to other characters.

The history of art is divided into architecture, sculpture and painting. Painting is classified according to countries and periods. Every subdivision has another principle. To carry through a system for an entire domain according to one principle would be impracticable and barren.

So it is in every field; crystallography is no exception.

8. *One can derive the thirty-two classes (deductively) from the principle of symmetry without being acquainted with the forms which Nature offers. Since there are no other possibilities, natural structures, both known and as yet unknown, must fit into the system.* This is a dangerous argument. It releases the crystallographer from his duty of occupying himself with Nature, for the deductively derived system already contains everything that is possible. Experience will and can contribute nothing new beyond, at most, a few hitherto overlooked examples. Why then pursue the investigation of Nature? Everything worth knowing is already in the system.

But there is only one way to the truth: approach Nature and learn to understand her language and read her writing. Her hieroglyphics will become words, and these will range themselves in melodies singing the exalted song of the beauty and harmony of ever-regenerating creation.

9. *A more important relation exists between the thirty-two classes and the physical properties of crystals than between the crystal systems and the physical properties.* This rather widespread assumption is, as far as I can judge, without application.

We proceed to the second question.

Question (b): **Which of the two classifications is dispensable, A or B?**

The answer is unequivocal: **B can be dispensed with, A cannot.**

Crystallography is the science of crystals as shown by Nature; it is a natural science served by a system. Each crystal must be placed in the system, and for this purpose must be measured, projected and discussed. In this way we arrive first at the crystal system (A), and then at the division, which means that the path

leads from A to B, not from B to A. Thus A cannot be dispensed with.

We have reached the conclusion; the decision is:

System A is to be retained, B set aside.

RETROSPECT AND HISTORY

The arguments against B, particularly 1-4, are so conclusive, that it appears incomprehensible that so large a proportion of our mineralogical teachers, among them distinguished, even prominent men, have decided in favor of B.

We will try to trace this historically.

The thirty-two classes were founded by A. Gadolin (1867), and introduced to wider circles by P. Groth (1895), who says:⁹

"The systematic treatment of crystallography developed above proceeded from the simple crystal forms, *i.e.* those with the lowest grade of symmetry, and, by addition of further symmetry elements, gradually reached the most symmetrical of the thirty-two classes, each of which represents an independent unity characterized by definite symmetry relations.

"The gathering of certain symmetry classes into one group (crystal system), which was used for ready survey, rests on purely practical considerations, and is, in a certain sense, even arbitrary. These groups constitute the foundation of the earlier crystallographic presentations."

At that time P. Groth stood in high esteem and others followed him. Respected mathematicians (Schöndliess) consolidated the system. One admired mathematics which was able to review a rich natural science (crystallography) and give it a system, without having concerned itself in detail with crystals by way of natural research. One forgot that crystallography is a natural science and not a chapter of mathematics.

Crystals cannot be understood, no more than lizards or frogs, or classified according to their characters, without studying them in detail. If we classify without detailed study we go astray, for Nature is always right.

We have had this case once before in crystallography. It was believed that crystal forms were to be seen in the regular bodies of stereometry; this was true in the case of the tetrahedron, the cube, the octahedron, and the rhombic dodecahedron, but failed with the pentagonal dodecahedron. That way was abandoned, and the same should be done again to-day.

⁹ *Physikalische Kristallographie*, Ed. III, p. 523, 1895 (trans.).

The introduction of the thirty-two classes by P. Groth was welcomed and greeted as an advance. How did this come about?

At that time morphology was concerned only with plane-faced crystals; it consisted of one-circle measurement of crystals, calculation with spherical trigonometry, and drawing on the axes, so difficult an art that only masters like Gerhard Vom Rath could handle complicated cases. Thereby the catalogues of forms expanded, and drawings and tables multiplied to such an extent that they could not be reviewed. The morphology of that time also lacked important objectives. Stagnation supervened.

Then the *petrography of thin sections*, with its wealth of new appearances and new problems, appeared as a new light. The mineralogists threw themselves into the new field. The young men went to F. Zirkel in Leipzig and to H. Rosenbusch in Heidelberg. The polarizing microscope replaced the goniometer.

Now the forms of crystals were no longer interesting, only the optical properties as they appeared in rock-sections in polarized light. In his *Physikalische Kristallographie* Groth attempted to bring together in easily understandable form such theory of crystal optics as was required for petrography.

The crystal systems interested the petrographers only as the carriers of the symmetry which could be recognized optically in the crystal grains of thin sections. In particular one was concerned with the distinction between monoclinic feldspar (orthoclase) and triclinic feldspars (plagioclase), between rhombic amphibole and pyroxene from monoclinic and triclinic representatives. Symmetry now became the leading criterion; the monoclinic system became the monosymmetric and the triclinic the asymmetric.

The crystal systems were classified and defined according to the number of symmetry planes: asymmetric, 0 symmetry plane; monosymmetric, 1; rhombic, 3; tetragonal, 1 principal and 4 common symmetry planes; hexagonal, 1 principal and 6 common symmetry planes; regular, 3 principal and 6 common symmetry planes. But these definitions failed for the divisions of the crystal systems, for the hemihedrisms, the tetartohedrisms, and the hemimorphisms, even with the models themselves. The tetrahedron lacked the symmetry planes demanded by the regular system, the rhombohedron those of the hexagonal system. Then appeared the thirty-two Gadolinian classes which took into consideration also the hemihedrisms, tetartohedrisms and the hemimorphisms. They were wel-

came as the salvation for the symmetry principle of the crystallographic system. The discrepancies of the divisions disappeared; but there remained against this system the above-detailed serious counter-arguments, especially point 1.

In the meantime petrography developed further; it became a great independent science; it concerned itself largely with magmatic formations and structures; it assisted in the problems of geology. Petrography regarded crystallography, especially morphology, as a preparation to its own problems, and welcomed a system which relieved it of the labor of pursuing studies in morphology. Such a system was found and retained in the symmetry classes.

Then a new epoch-making discovery entered our science, namely, the Laue diagrams with Röntgen rays. Now it was believed that the internal particle-structure of crystals was concretely visible; and thereupon the physicists and the mathematicians rushed into the new field of research, especially since the Röntgen diagrams gave information of structures far beyond those of crystals, and entered and assisted in technical fields.

The glitter of the new invention, eagerly pursued by excellent people, outshone the gentle light of the quiet, but steadily progressing study of crystal-morphology.

The conclusion reached was as follows: Röntgenography shows the internal structure of crystals from which the forms may be derived. We can do without morphology; at best it contributes only confirmation and supplementary information. The morphologists are old-fashioned folk; their methods are superseded. They have their place since we can take our material to them to have it arranged, but we, the physicists and the mathematicians, pursue the true science.

But it is not so. Röntgenography is an important chapter of crystallography. Its development to-day engages many investigators. Crystallography, as the complete science of crystals, will thankfully receive the valuable results of this research, when they are clarified, and fit them in its structure.

Happily, crystallography has in the meantime made such progress in its main field, morphology, and in the extension of its problems, and is thus so much strengthened, that it is in the position to incorporate serviceably into the whole single fields, such as röntgenography and crystal optics. This will eventually come about.

As long as the Röntgenographers, occupied with the cultivation of their special field, do not search for the relationship of their field with the entire science, a system which relieves them of the trouble of entering morphology is welcome. In this way system B serves them. But when the work in the special field has progressed to such a point that, after overcoming the present lack of agreement, it can be fitted into the whole, then that system which best serves the whole will be generally adopted. That is system A.

DETERMINATION OF CHROMIUM IN RUBY¹

WM. J. O'LEARY AND JACOB PAPISH, *Department of Chemistry,
Cornell University.*

A search of the literature for data on the chromium content of the natural ruby revealed that none of the recorded analyses of ruby include this element; on the contrary, it has long been taken for granted that an attempt at such a determination is futile. Fremy,² in writing about the ruby states that an analysis cannot show the real composition of the mineral; synthesis, however, serves to distinguish between essential and accessory constituents. This statement is a conclusion drawn from extensive experimentation, and forms the basis for the assertion that the color of naturally occurring ruby is due to chromium. Wöhler and Kraatz-Koschlau³ found that chromium in natural ruby is present in amounts too small to be determined by analytical methods. Doelter⁴ also states that the chromium content of ruby is so small that it cannot be quantitatively determined. Doelter and Leitmeier⁵ say that only traces of chromium can be detected in ruby. It was, therefore, deemed expedient to find out whether an analytical method could be adapted to the determination of chromium in ruby.

A number of gravimetric methods were tried to determine chromium in known mixtures of the oxides of aluminum and chromium, but they were found unreliable; results obtained with duplicate samples were not concordant, and were always low. It was next decided to test the applicability of a standard volumetric method, in which the chromium is oxidized to chromate, and is titrated with a standard solution of ferrous ammonium sulfate. In order to duplicate the conditions under which the rubies were later to be analyzed after fusion with large amounts of potassium hydrogen sulfate, the following mixtures were prepared which contained

¹ This article is a corollary of experiments supported by a grant from the Heckscher Foundation for the Advancement of Research, established by August Heckscher at Cornell University.

² Fremy, *Synthèse du Rubis*, p. 1, Paris (1891).

³ Wöhler and Kraatz-Koschlau, *Tschermak's miner. petrog. Mitt.*, **18**, 456 (1899).

⁴ Doelter, *Sitzb. Wissen. Akad. Wien. Abt. I*, **117**, 819 (1908); *Die Farben der Mineralien*, p. 28, Braunschweig (915).

⁵ Doelter u. Leitmeier, *Handbuch der Mineralchemie*, Vol. 3, Part II, p. 443, Leipzig (1926).

known amounts of chromium added from a previously analyzed solution of chromic acid:

A. 15 gm. of potassium hydrogen sulfate, 1 gm. of aluminum oxide, and 0.00128 gm. of chromium;

B. 15 gm. of potassium hydrogen sulfate, 1 gm. of aluminum oxide, and 0.00051 gm. of chromium;

C. 15 gm. of potassium hydrogen sulfate, 0.5 gm. of aluminum oxide, and 0.00025 gm. of chromium.

Each of these mixtures was fused in a platinum crucible. A and B were taken up in 150 c.c. of nitric acid (1:2), while C was taken up in 75 c.c. They were then oxidized with sodium bismuthate in the usual way,⁶ and were titrated with one-hundredth normal KMnO_4 and $\text{FeSO}_4 \cdot (\text{NH}_4)_2\text{SO}_4 \cdot 6\text{H}_2\text{O}$. The results, listed in Table I, show that the discrepancies are negligible and within the limits of experimental error.

TABLE I
TEST DETERMINATIONS ON KNOWN AMOUNTS OF CHROMIUM IN THE
PRESENCE OF SALTS OF ALUMINUM AND POTASSIUM

Mixture	Gm. of chromium used	Gm. of chromium determined by titration
A	0.00128	0.00124
B	0.00051	0.00048
C	0.00025	0.00021

As this method proved to be satisfactory, rubies from several different localities were analyzed for their chromium content in a similar way. All these rubies were chosen particularly for their color, with the object of securing typical specimens. They were first crushed in a "diamond steel" mortar so as to pass a 200 mesh sieve, and were carefully gone over with a magnet to remove particles of steel. It was noticed that the sieve invariably retained the occasional chips that were broken off of the mortar during the process of crushing. Samples of the pulverized material were then fused in a platinum crucible with fifteen times their weight of potassium hydrogen sulfate, and were taken up in water. The fusions in nearly all cases were complete the first time, but occasionally a small insoluble residue had to be re-fused with potassium

⁶ Mahin, *Quantitative Analysis*, p. 467, New York (1924).

hydrogen sulfate before proceeding with the determination. The results of these analyses are given in Table II.

TABLE II
CHROMIUM CONTENT OF RUBIES

Ruby No.	Place of origin	Weight of sample, gm.	Percent Cr	Percent Cr_2O_3
1	Mysore, India	0.8000	0.167	0.244
		0.2000	0.171	0.250
2	Ural Mountains	0.4500	0.121	0.174
		1.0004	0.119	0.177
3	Mysore, India	1.0000	0.162	0.237
		1.0000	0.156	0.228
4	Zoutpansberg, Transvaal	1.0000	0.130	0.190
		1.1000	0.131	0.191
5	Macon County, North Carolina	0.5000	0.068	0.099
		0.4000	0.070	0.102

No. 1. Several small, deep red crystals, uniform in color, translucent, containing inclusions (probably zircon).

No. 2. Several deep red crystals, uniform in color, translucent to subtransparent.

No. 3. Several deep red crystals, uniform in color, translucent.

No. 4. Deep red crystal, opaque.

No. 5. Deep red crystal, translucent; basal and a prismatic face completely covered with a heavy layer of fuchsite.

SUMMARY

The chromium content of naturally occurring ruby has been determined by a standard analytical method.

The rubies that were analyzed were found to contain between 0.10 and 0.25 percent chromic oxide.

BERYLLIUM IN MINERALS AND IGNEOUS ROCKS

HENRY S. WASHINGTON, *Geophysical Laboratory.*

In a recent paper C. Palache and L. H. Bauer¹ record the discovery of the presence of beryllium in vesuvianite from Franklin, New Jersey. This observation is of great interest, not only because it suggests possibly a new source of supply for beryllium, as was pointed out by the authors, but it also simplifies the chemical formula of vesuvianite, which has been more or less uncertain. In addition, this discovery indicates the importance of determining beryllium in various silicate minerals in which it has not been previously looked for or its presence suspected. In the ordinary course of silicate analysis beryllia (BeO) is precipitated with and weighed as alumina (Al_2O_3), unless it is separated from this constituent, which demands a somewhat complicated procedure. Indeed, the authors say: "It seems highly probable that beryllium is generally present in this mineral [vesuvianite] but has not been recognized, being determined as alumina."

In this connection attention may be called to the fact that the norm of certain rocks, nephelite syenites for the most part, show an excess of alumina ("normative corundum") over that needed for the feldspars and nephelite, which can not be accounted for by the minerals present in the rock.

Several examples of this are: the nephelite syenite of Wausau, Wisconsin;² the nephelite aplite of the Los Islands;³ and the nephelite syenite of Almunge, Sweden.⁴ None of these rocks contain biotite or any other mineral that would serve to explain the excess of alumina, "C" being given in each case.⁵

Other rocks that show an excess of alumina contain biotite or muscovite, but, according to the descriptions, the amount of mica is insufficient to account for the normative excess of alumina. Examples of such rocks are: the nephelite syenite of East Cape, Siberia;⁶ the nephelite syenite of Vizagapatam, India;⁷ and that of Assynt, Scotland.⁸

¹ Palache and Bauer, *Am. Mineral.*, **15**, 30, 1930.

² Weidman, *Jour. Geol.*, **12**, 552, 1904. (C=1.53).

³ Lacroix, *Nouv. Arch. Mus.*, **3**, 105, 1911. (C=1.84).

⁴ Quensel, *Bull. Geol. Inst. Upsala*, **12**, 185, 1914. (C=5.30).

⁵ The norms of these rocks are to be found in *U. S. Geol. Survey, Prof. Paper 99*.

⁶ Washington, *Am. Jour. Sci.*, **13**, 176, 1902. (C=2.96).

⁷ T. L. Walker, *Rec. Geol. Survey India*, **36**, 21, 1908. (4.08).

⁸ Shand, *Trans. Edinburgh Geol. Soc.*, **9**, 399, 1910. (C=3.88).

In some, or most, of these cases the author in describing the rock has noted the presence of an excess of alumina and has offered various explanations to account for it.

Some years ago it was suggested⁹ that this excess of alumina in nephelite syenites, in which apparently there was no mineral present to account for it, might be due to the presence of beryl, which had been mistaken for nephelite, the beryllia having been weighed with and thought to be alumina.

Beryl and nephelite closely resemble each other in many respects. In thin section they are both colorless, without cleavage, and untwinned. They are both hexagonal in crystallization. Optically they are both negative, with very similar refractive indices and birefringence, especially for beryl low in alkalis.¹⁰ Indeed, optically they are so much alike that they might readily be mistaken for one another, if optical characters alone are depended on and if the examination is not very painstaking and exact. Both minerals, also, are usually associated with rocks high in soda.¹¹

The two minerals, however, differ much in habit. Nephelite is usually anhedral and interstitial in plutonic rocks, but it forms euhedral phenocrysts in such rocks as phonolite; while beryl occurs typically in well-formed, generally prismatic crystals, although it is also granular to compact. It is said not to occur in microscopic crystals.¹² They differ, also, in that nephelite occurs only in igneous rocks, either plutonic or effusive, in some cases the former having been metamorphosed to gneiss; while beryl is most commonly observed in granitic pegmatites, but it also occurs in metamorphic rocks. Beryl is usually associated with quartz, but not with nephelite, the latter never being associated with primary quartz.

But beryl is not the only beryllium-bearing mineral that is to be considered in this connection. Indeed, its general association with quartzose pegmatities, rather than with nephelite, if this be in reality not occasionally possible, is adverse to the idea that beryl may account for the excess of alumina, although it is not impossible that it holds good in some cases.

⁹ Washington, *Trans. Am. Inst. Min. Eng.*, **39**, 753, 1909.

¹⁰ Cf. Ford, *Am. Jour. Sci.*, **30**, 128, 1910; Lacroix, *Min. de Madagascar*, **1**, 545, 1922.

¹¹ Clarke and Washington, *U. S. Geol. Survey, Prof. Paper* **127**, 103, 1924.

¹² Rosenbusch-Mügge, *Mikr. Phys.*, **I**, (1), 276, 1925. It is noteworthy that beryl is not mentioned in earlier editions of Rosenbusch.

Bauer's observation that a notable amount of beryllium is present in the vesuvianite of Franklin, and that it is probably present in other vesuvianites, would serve to explain the normative excess of alumina in the Almunge nephelite syenite.¹³ This excess amounts to 5.30 per cent, and Quensel found it difficult to account for it, as no corundum is present and there is but a trace of biotite. But much of this syenite, including the specimen analyzed, contains a considerable amount of vesuvianite. If this is beryllium-bearing, like that of Franklin, which, as indicated by Palache and Bauer, is likely to be the case with other vesuvianites, the explanation of the excess of alumina is obvious—the beryllia has been weighed with and reported as alumina, both in the rock and in the calculation of the norm. Quensel gives no figures as to the mode of this specimen, so that quantitative estimates are impossible, but if the quantity of vesuvianite present is like that shown in his illustration of a thin section (Plate IX, Fig. 1), and if the percentage of beryllium in the vesuvianite is equal to that found at Franklin, there should be easily enough vesuvianite present to account for the 5.30 per cent excess of alumina. Incidentally, the normative anorthite is, at least in large part, to be referred to the vesuvianite, as the feldspars are said to be "principally" soda-potash feldspars, and there is but little pyroxene.

It is also possible that the presence of beryllium-bearing vesuvianite may account for the excess of alumina in the Vizagapatam nephelite syenite.¹⁴ The amount of this is so large ($C=4.08$) that Walker suggests the possible presence of corundum, although none was seen in the thin sections. The feldspar in this rock shows certain peculiarities, to which Walker calls attention. "No twinning is to be observed," and the feldspar breaks up, between crossed nicols, into two parts, a series of similarly oriented lenses in a groundmass of uniform grain.

Walker found that 38.84 per cent of the rock powder was soluble in warm dilute hydrochloric acid, "corresponding to a nepheline content of about 37 per cent," about 1 per cent of calcite being present. This result is interesting and possibly significant, because only 23.57 per cent of nephelite is present in the norm. This discrepancy of about 13 per cent, as well as the excess of alumina, is

¹³ Quensel, *Bull. Geol. Inst. Upsala*, **12**, 186, 1924; *Neues Jahrb.*, **1915**, 203.

¹⁴ T. L. Walker, *Rec. Geol. Surv. India*, **36**, 22, 1908.

explicable if a beryllium-vesuvianite, partially soluble in acid, is present in the rock, in analogy with the Almunge syenite.

Vesuvianite is partially decomposed by hydrochloric acid, according to Dana and other authorities, while, according to others, it is not attacked. Such divergence might be expected, in view of the great variation in the composition of the mineral. Similarly, the range in the refractive indices is large, from about 1.705 to 1.732 for ω . Also, while most vesuvianites are optically negative, some varieties are positive.

Dr. Tom. F. W. Barth has kindly examined a thin section of my specimen of the nephelite syenite of East Cape, Siberia, which shows 2.96 percent of excess alumina in the norm,¹⁵ but no vesuvianite could be detected, so that the excess alumina is most probably to be ascribed to the hydronephelite that is present, as was suggested in the original description. According to Thugutt¹⁶ hydronephelite is a mixture of natrolite, hydrargillite, and a little diaspore. Whether this is the case, or if the mineral has the composition originally assigned to it by Clarke, it contains an excess of alumina over that needed for nephelite or feldspar.

But besides vesuvianite there are several other minerals that are now known to contain beryllium as an essential constituent in which its presence was not suspected at first. Thus, barylite was first described as a barium aluminum silicate, but was found by Aminoff¹⁷ to be a silicate of barium and beryllium, the beryllia having been in the first analyses weighed with and mistaken for alumina, the mineral as analyzed by Aminoff containing 16.01 per cent of BeO and only 0.05 of Al₂O₃. This was confirmed by Bauer in the barylite of Franklin, New Jersey.¹⁸

There are several other minerals that are not usually considered as containing beryllium, but in some varieties of which it has been shown to be present in recent analyses. Among these are: a fluorine-free humite of the Allalin Region in Switzerland,¹⁹ titanolite of the Val d'Ala in Piedmont,²⁰ and titanolite of Christian-

¹⁵ Washington, *Am. Jour. Sci.*, **13**, 175, 1902. This specimen is now in the Petrographical Reference Collection, of the U. S. National Museum.

¹⁶ Thugutt, *Neues Jahrb., Beil. Bd.*, **9**, 612, 1895; *Neues Jahrb.*, **1910**, I, 27.

¹⁷ G. Aminoff, *Geol. För. Förh. Stockholm*, **45**, 124, 1923.

¹⁸ Palache and Bauer, *Am. Mineral.*, **15**, 32, 1930.

¹⁹ Jannasch and Locke, *Zeit. Anorg. Chem.*, **7**, 92, 1894. R. W. Schäfer, *Tsch. Min. Pet. Mitth.*, **15**, 126, 1896.

²⁰ Zambonini, *Bull. Soc. Franç. Minér.*, **42**, 269, 1919.

sand in Norway.²¹ Machatschki²² speaks of the Val d'Ala mineral as clinohumite, and thinks that the beryllium replaces or functions as silicon.

From these examples it is clear that beryllium is almost certainly more abundant and wide-spread than it has hitherto been thought to be, and that a former estimate that about 0.001 per cent of beryllium is present in the earth's crust²³ is too low. Also, the questions of the replacement of silicon or magnesium by beryllium in humite and olivine, and of calcium in vesuvianite, as well as the simplification of the formula of the latter, are of great interest and of some theoretical importance.

It would thus appear to be advisable, for several reasons, to look for and determine beryllium in silicate minerals and in igneous rocks more often than has been done in the past. In this we would be following Hillebrand's "Plea for greater completeness in chemical rock analysis," a paper published as early as 1894,²⁴ in which he stresses the importance of the determination of the rare elements in rocks for the solution of broad petrological problems. The importance of such determinations is also pointed out by Clarke²⁵ and by the present writer.²⁶

The separation of beryllia from alumina is not difficult and there are several satisfactory methods, that of Parsons and Barnes²⁷ being one of the best and the one most frequently used, while a more recent method is that using 8-hydroxyquinoline.

²¹ Barth, *Norsk Geol. Tidsskr.*, 8, 99, 1925.

²² Machatschki, *Neues Jahrb., Abt. A*, 1930, 198.

²³ Clarke and Washington, *U. S. Geol. Survey, Prof. Paper* 127, 20 and 25, 1924.

²⁴ Hillebrand, *Jour. Am. Chem. Soc.*, 16, 90, 1894. Also, *U. S. Geol. Survey, Bull.* 422, 18, 1910.

²⁵ F. W. Clarke, *U. S. Geol. Survey, Bull.* 591, 17, 1915.

²⁶ Washington, *U. S. Geol. Survey, Prof. Paper* 99, 16, 1917. *Chemical Analysis of Rocks*, 4th ed., 1930, 7.

²⁷ Parsons and Barnes, *Jour. Am. Chem. Soc.*, 28, 1589, 1906. Cf. Hillebrand-Lundell, *Applied Inorganic Analysis*, 1929, 405. Washington, *Chemical Analysis of Rocks*, 1930, 273.

BOOK REVIEW

TABLES FOR THE DETERMINATION OF MINERALS BY MEANS OF THEIR PHYSICAL PROPERTIES. Second Edition. Edward H. Kraus and Walter F. Hunt, IX+261 pages. McGraw-Hill Book Co., New York, \$3.00.

This second edition of the above tables contains 250 mineral species, which number is quite large enough to include all the important ore and rock-forming minerals and yet not enough to over-load the tables, thus complicating their use and confusing the individual.

The arrangement is well thought out and practical. The descriptions are concise and to the point.

Color, the most variant of the physical properties of non-metallic minerals, has been carefully considered, and the variations, even when rare, are put in their proper places. Particularly useful are the remarks under Characteristics and Associates. Also there has been added a table arranged according to their specific gravity, including the chemical formula of each species.

With the instructions in the introduction and the glossary, even the inexperienced in mineralogy should quickly learn to use the tables successfully.

A. H. PHILLIPS

PROCEEDINGS OF SOCIETIES NEW YORK MINERALOGICAL CLUB

Minutes of the November Meeting.

A regular meeting of the New York Mineralogical Club, with 63 members present, was held at the American Museum of Natural History on the evening of Nov. 19, 1930, with President Frederick I. Allen in the chair.

Mr. James A. Taylor of Glen Ridge, N.J.; Dr. R. B. Sosman and Mr. H. C. Lee of Kearny, N. J.; Mr. William Casperson of Paterson, N. J.; and Mr. E. J. Rouy of Clifton, N. J. were elected to membership.

A report was made of the Election Day field trip of the Club to the quarry at West Paterson, N. J. The excursion was largely attended and unusually successful, eighteen species of minerals being reported as found.

A number of old books on mineralogy were exhibited and discussed by various members.

The address of the evening was delivered by Professor Alfred C. Hawkins of Rutgers University. His subject dealt with the appearance of crystals of various types under the microscope. He mentioned a number of interesting simple and twinned crystals, observed during various studies of organic and inorganic chemical compounds, and then proceeded with a brief discussion of the common rock-forming minerals as seen in thin sections of rocks.

Special attention was given to a mineral found at West Paterson, which shows the characteristics of strontianite, and to the interesting crystal habits of polyhalite.

The lecture was illustrated by means of lantern slides from photomicrographs. A rising vote of thanks was extended to the speaker.

JAMES F. MORTON, *Secretary*

NEWARK MINERALOGICAL SOCIETY

ANNUAL REPORT OF THE SECRETARY

Newark, N. J., November 2, 1930.

To the Members of the Newark Mineralogical Society:

Ladies and Gentlemen:—

The Annual report of the Secretary of the Newark Mineralogical Society is presented. This report covers the fiscal year beginning November 3, 1929, and ending November 2, 1930, and includes such facts as the secretary thinks will be of interest to the members.

1. MEMBERSHIP

There were on the roll of members, November 3, 1929.....	85
Admitted to membership during the year.....	8
	Total 93
Lost to the roll—Resigned.....	1
Died.....	1
Dropped.....	2
	Total deductions from the roll 4
On the roll November 2, 1930.....	89

2. OFFICERS AND TRUSTEES

At the annual meeting of November 3, 1929, the following officers were elected.

President—John A. Grenzig of Brooklyn, N. Y.

Vice-president—George E. Carpenter of Newark, N. J.

Secretary—Herbert L. Thowless of Newark, N. J.

Treasurer—Herman M. Lehman of Newark, N. J.

To complete the Board of Trustees, Mrs. Victor C. Gilbert of Newark was elected, for three years.

The Board comprises the four officers; Mr. Charles W. Hoadley, whose term will expire in November, 1930; Mr. Paul Walther, whose term will expire November, 1931 and Mrs. Victor C. Gilbert, whose term will expire November, 1932.

3. COMMITTEES

The president appointed the following committees:

Membership

Herbert L. Thowless, Chairman

Richard P. Milburn

George E. Carpenter

Josephine Morlock

Paul Walther

Program

John A. Grenzig

Publicity

Herbert L. Thowless

Outings

All members of the Society.

4. MEETINGS AND PROGRAMS

During the past year, the Society held eight business and program meetings. A brief mention of each meeting and the special program will be of interest.

107th. meeting, November 3, 1929. This was also the annual meeting. The program consisted of a fine talk on "*The Minerals of Franklin, New Jersey*," by Mr. L. H. Bauer, of the chemical department of the New Jersey Zinc Company. The talk was illustrated with many fine specimens from Franklin.

108th. meeting, December 1, 1929. A regular business meeting, with 22 members and 2 guests present. The program consisted of a "*Symposium on Agates*," well illustrated. Mr. Paul Walther; Mr. Louis Reamer; Mr. Charles W. Hoadley; Mr. Carl Dauterman; Mr. Manyard; Mr. Algor; Mr. Thowless; Dr. Schroeder and the President took part.

109th. meeting, January 5, 1930. General business meeting. The program consisted of a very interesting talk by Mr. J. W. Radu on "*Misrepresentation of Gems and Minerals*," illustrated by specimens of emerald, garnet and other gems. Exhibitions of specimens were made by Dr. Schroeder, Mr. Walther and the President. Mr. Hoadley spoke on the "faking" of minerals and Mr. Allen on the index of refraction of minerals. Nineteen members and 3 guests were present.

110th. meeting, February 2, 1930. Business session devoted partly to the matter of the cleaning of the minerals at the Newark Technical School. The minerals were later cleaned and classified. The program consisted of a paper on "*Calcite*" by Dr. Schroeder. Mr. Allen also explained the planes and axes of calcite. Specimens were exhibited by Mr. Maynard and the President. Fifteen members and 1 guest in attendance.

111th. meeting, March 2, 1930. The program, following the business session, consisted of a talk on the "*Minerals of New Jersey*" by William H. Broadwell. Mr. Broadwell spoke about the minerals of 27 localities and exhibited specimens from each locality. Brief talks on other mineral localities followed, with exhibitions of specimens. Thirteen members and 3 guests were present.

112th. meeting, April 6, 1930. Short business session, followed by a talk on the "*Minerals of the Constitution State*" by Mr. Charles W. Hoadley. The speaker exhibited specimens from Connecticut. Fifteen members and 10 guests were present.

113th. meeting, May 4, 1930. Short business session followed by a most excellent talk on "*Crystallography*" by Mr. Frederick I. Allen. The speaker made use of models to illustrate the various forms. Twelve members and 5 guests were present.

114th. meeting, October 6, 1930. The business session was followed by short descriptive talks by a number of the members, together with an "*Exhibition of Minerals Collected During the Summer*." Among the members who described specimens were Mr. Bates; Mr. Carpenter; Mr. Reamer; Mr. Walther; Dr. Hawkins and the President. Fourteen members and 4 guests were present.

5. PROGRAMS AND HIKES

No programs on a large scale were undertaken during the past year and the Outing Committee was not able to arrange for any outdoor trips. It is hoped that the coming year will see more activity along these lines of Society work. Many localities are now closed, or no specimens can be found, or else they are too far away for the members to make the necessary trips.

Respectfully submitted,
HERBERT L. THOWLESS, *Secretary*